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Forthcoming Papers

Special Volume on Economic Principles of Multi-Agent Systems. Guest Editors: Craig Boutilier, Yoav Shoham and Michael P. Wellman

D. Poole, The Independent Choice Logic for modelling multiple agents under uncertainty

Inspired by game theory representations, Bayesian networks, influence diagrams, structured Markov decision process models, logic programming, and work in dynamical systems, the independent choice logic (ICL) is a semantic framework that allows for independent choices (made by various agents, including nature) and a logic program that gives the consequence of choices. This representation can be used as a specification for agents that act in a world, make observations of that world and have memory, as well as a modelling tool for dynamic environments with uncertainty. The rules specify the consequences of an action, what can be sensed and the utility of outcomes. This paper presents a possible-worlds semantics for ICL, and shows how to embed influence diagrams, structured Markov decision processes, and both the strategic (normal) form and extensive (game-tree) form of games within the ICL. It's argued that the ICL provides a natural and concise representation for multi-agent decision-making under uncertainty that allows for the representation of structured probability tables, the dynamic construction of networks (through the use of logical variables) and a way to handle uncertainty and decisions in a logical representation.

S. Russell, Rationality and intelligence

The long-term goal of our field is the creation and understanding of intelligence. Productive research in AI, both practical and theoretical, benefits from a notion of intelligence that is precise enough to allow the cumulative development of robust systems and general results. The concept of *rational agency* has long been considered a leading candidate to fulfill this role. This paper outlines a gradual evolution in the formal conception of rationality that brings it closer to our informal conception of intelligence and simultaneously reduces the gap between theory and practice. Some directions for future research are indicated.

S. Kraus, Negotiation and cooperation in multi-agent environments

Automated intelligent agents inhabiting a shared environment must coordinate their activities. Cooperation—not merely coordination—may improve the performance of the individual agents or the overall behavior of the system they form. Research in Distributed Artificial Intelligence (DAI) addresses the problem of designing automated intelligent systems which interact effectively. DAI is not the only field to take on the challenge of understanding cooperation and coordination. There are a variety of other multi-entity environments in which

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the entities coordinate their activity and cooperate. Among them are groups of people, animals, particles, and computers. We argue that in order to address the challenge of building coordinated and collaborated intelligent agents, it is beneficial to combine AI techniques with methods and techniques from a range of multi-entity fields, such as game theory, operations research, physics and philosophy. To support this claim, we describe some of our projects, where we have successfully taken an interdisciplinary approach. We demonstrate the benefits in applying multi-entity methodologies and show the adaptations, modifications and extensions necessary for solving the DAI problems.

T.W. Sandholm and V.R. Lesser, Coalitions among computationally bounded agents

This paper analyzes coalitions among *self-interested* agents that need to solve *combinatorial optimization problems* to operate efficiently in the world. By colluding (coordinating their actions by solving a joint optimization problem) the agents can sometimes save costs compared to operating individually. A model of *bounded rationality* is adopted where computation resources are costly. It is not worthwhile solving the problems optimally: solution quality is decision-theoretically traded off against computation costs. A normative, application- and protocol-independent theory of coalitions among bounded-rational agents is devised. The optimal coalition structure and its stability are significantly affected by the agents' algorithms' performance profiles and the cost of computation. This relationship is first analyzed theoretically. Then a domain classification including rational and bounded-rational agents is introduced. Experimental results are presented in vehicle routing with real data from five dispatch centers. This problem is NP-complete and the instances are so large that—with current technology—any agent's rationality is bounded by computational complexity.

Y. Shoham and M. Tennenholtz, On the emergence of social conventions: modeling, analysis, and simulations

We define the notion of *social conventions* in a standard game-theoretic framework, and identify various criteria of consistency of such conventions with the principle of individual rationality. We then investigate the emergence of such conventions in a stochastic setting; we do so within a stylized framework currently popular in economic circles, namely that of *stochastic games*. This framework comes in several forms; in our setting agents interact with each other through a random process, and accumulate information about the system. As they do so, they continually reevaluate their current choice of strategy in light of the accumulated information. We introduce a simple and natural strategy-selection rule, called *highest cumulative reward* (HCR). We show a class of games in which HCR guarantees eventual convergence to a rationally acceptable social convention. Most importantly, we investigate the efficiency with which such social conventions are achieved. We give an analytic lower bound on this rate, and then present results about how HCR works out in practice. Specifically, we pick one of the most basic games, namely a basic *coordination* game (as defined by Lewis), and through extensive computer simulations determine not only the effect of applying HCR, but also the subtle effects of various system parameters, such as the amount of memory and the frequency of update performed by all agents.

D. Koller and A. Pfeffer, Representations and solutions for game-theoretic problems

A system with multiple interacting agents (whether artificial or human) is often best analyzed using *game-theoretic* tools. Unfortunately, while the formal foundations are well-established, standard computational techniques for game-theoretic reasoning are inadequate for dealing with realistic games. This paper describes the *Gala system*, an implemented system that allows the specification and efficient solution of large imperfect information games. The system contains the first implementation of a recent algorithm, due to Koller, Megiddo, and von Stengel. Experimental results from the system demonstrate that the algorithm is exponentially faster than the standard algorithm in practice, not just in theory. It therefore allows the solution of games that are orders of magnitude larger than were previously possible. The system also provides a new declarative language for compactly and naturally representing games by their rules. As a whole, the Gala system provides the capability for automated game-theoretic analysis of complex real-world situations.

R.I. Brafman and M. Tennenholtz, Modeling agents as qualitative decision makers

We investigate the semantic foundations of a method for modeling agents as entities with a mental state which was suggested by McCarthy and by Newell. Our goals are to formalize this modeling approach and its semantics, to understand the theoretical and practical issues that it raises, and to address some of them. In particular, this requires specifying the model's parameters and how these parameters are to be assigned (i.e., their *grounding*). We propose a basic model in which the agent is viewed as a qualitative decision maker with beliefs, preferences, and decision strategy; and we show how these components would determine the agent's behavior. We ground this model in the agent's interaction with the world, namely, in its actions. This is done by viewing model construction as a constraint satisfaction problem in which we search for a model consistent with the agent's behavior and with our general background knowledge. In addition, we investigate the conditions under which a mental state model exists, characterizing a class of "goal-seeking" agents that can be modeled in this manner; and we suggest two criteria for choosing between consistent models, showing conditions under which they lead to a unique choice of model.